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USER'S GUIDE

User's Guide: Ground-Penetrating Radar

by

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U.S. Army Center for Public Works
Alexandria, VA 22310-3860

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This report provides a description of ground-penetrating radar used to determine the thickness of different layers of a pavement structure and the location of water and sewer lines under a roadway system. Ground-penetrating radar consists of a device that emits a short pulse of electromagnetic energy and is able to determine the presence or absence of a target by examining the reflected energy from that pulse. In the case of a pulse fired into a pavement structure, the electromagnetic wave travels until it meets with a dielectric discontinuity. A portion of the wave is reflected by this discontinuity, and the balance continues to travel through the second medium.

The description, applicability, benefits, limitations, costs, recommended uses, and location of the demonstration for the ground-penetrating radar technology are discussed.

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Contents

1 Executive Summary

Description

Ground-penetrating radar is a system that uses short pulse radar to nondestructively measure the thicknesses of composite structural sections. The detection of an interface between two different materials by radar depends upon the partial reflection of incident energy at that interface. The amplitude of the reflected energy at the interface, with respect to the incident energy, is related to the relative dielectric constants of the two materials. Pavement layer thicknesses can be determined if the dielectric constants of the materials and the time required for radar waves to pass through the layers and return are known.

Applications

The typical applications of this technology are to investigate pavement structures to measure pavement thickness, identify thin or weak areas, locate voids beneath the pavement, measure overlay thickness, define areas of asphalt stripping, and determine the position of reinforcing steel in portland cement concrete (PCC). Results of this demonstration indicate that this system can also locate utilities buried to depths of approximately 4 feet.

Benefits

Ground-penetrating radar can be used to rapidly identify vertical structural characteristics and the general subsurface condition of a pavement structure. Results of this technology can replace costly time consuming pavement coring that is currently being used to determine pavement thicknesses and layer characteristics.

Limitations

The radar apparatus used in this technology is potentially a microwave radiation hazard, especially at high transmitted power levels. All personnel should stand clear of the region directly under the antenna (e.g., between the bottom of the antenna and the roadway surface) when the system is energized. Electromagnetic emissions from the radar apparatus could potentially interfere with commercial communications if the antenna is not properly oriented toward the ground.

Costs

The costs of implementing this technology are dependent upon mobilization of the equipment and crew to the survey site, the number and length of roads to be evaluated, and the volume of traffic on the roads. The greater the length and number of roads, the less the cost per mile. As traffic volume increases, the time required to collect data increases since the equipment-mounted van is difficult to maneuver in heavy traffic. The reason that the cost per mile decreases for large jobs is that the cost of mobilization, data reduction, and report production are relatively constant for any size project. Evaluation of the roads on a typical military installation will cost $15 - 20K.

Recommendations for Use

Ground-penetrating radar is recommended for use in determining thicknesses of pavement structures at military installations. In recent years in order to save money, pavement structures have been rehabilitated or strengthened to withstand expected traffic rather than construct new facilities. Selection of the correct rehabilitation strategy depends on a thorough evaluation of the existing pavement structure. Nondestructive testing, particularly using falling weight deflectometers, is the main tool for performing this evaluation. In order to back calculate

pavement layer strengths, the thickness of the pavement layers and the location of any bedrock close to the surface is required. Layer thicknesses are sometimes available from construction plan sheets but they are frequently either not available or not current. The alternative is spot coring which is time consuming, expensive, and requires traffic to be detoured during the coring operation.

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2 Preacquisition

Description of Ground-Penetrating Radar

Ground-penetrating radar has been used on a limited basis for approximately 10 years to determine thickness. Most of the efforts have been reasonably accurate (within 1/4 in.), but costs have been prohibitive. Within the last two years, the technology has improved due to improvements in computer technology to handle and process the vast amounts of data collected during a survey. The current systems are contained in a van size truck that travels at 5-40 miles per hour while collecting data. As the data is collected in the traffic lane, distances are measured and marked for a reference system. Output is furnished to the user in a report form that includes location and thicknesses of the surface and base course materials and the location and depth of utilities. This system has been demonstrated with great accuracy on test sections at WES. It has also been used in the Long Term Pavement Performance Studies of the Strategic Highway Research Program (SHRP).

At the network level, ground-penetrating radar can be used to rapidly identify vertical structural characteristics and the general subsurface condition of a pavement structure (e.g., to locate moisture, voids and other deteriorated areas using a small sample to represent the entire area). At the project level, a detailed evaluation of the extent and location of deteriorated areas (voids, stripped asphalt, wet areas, etc.) can be defined for use in planning the appropriate rehabilitation technique. Multiple passes (three to four per traffic lane) of the radar unit are required to obtain data for project level investigations.

Ground-penetrating radar consists of a device that emits a short pulse of electromagnetic energy and is able to determine the presence or absence of a target by examining the reflected energy from that pulse. In the case of a pulse fired into a pavement structure, the electromagnetic wave travels until it meets with a dielectric discontinuity. The dielectric discontinuity may be caused by a change in pavement layer, moisture within or beneath the layer, an air void, or some other change in the dielectric constant of the material in the path of

the wave. A portion of the wave is reflected by this discontinuity and the balance continues to travel through the second medium.

The amount of energy reflected at the discontinuity is a function of the wave impedance of the two materials. At the interface between materials with similar dielectric properties, such as two lifts of asphalt concrete pavement, most of the energy passes through the interface and very little is reflected back to the transmitter. Conversely, where the difference in dielectrics is significant, such as an asphalt layer over concrete or a base course, much of the energy is reflected to the transmitter and very little is passed to the next medium. This reflection phenomenon is the theoretical basis for the production of various radar signatures produced by different subsurface anomalies.

Application

In recent years, the emphasis on pavement construction has moved toward rehabilitating or strengthening existing structures rather than constructing new facilities. Selection of the correct rehabilitation strategy depends on a detailed evaluation of the existing pavement structure. Nondestructive testing using a falling weight deflectometer is the principal tool used to perform this evaluation. However, to perform the layer strength back calculation procedure, the thickness of pavement layers and presence of bedrock close to the surface is required. Layer thicknesses are sometimes available from construction plan sheets, but they are frequently either not available or not current. The alternative is spot coring which is expensive and time consuming. Ground-penetrating radar has the potential to accurately determine layer thicknesses, locate bedrock, and locate sewer and water lines buried to depths of approximately four feet.

Limitations/Disadvantages

The radar apparatus used in this technology is potentially a microwave radiation hazard, especially at high transmitted power levels. All personnel should stand clear of the region

directly under the antenna when the system is energized. Electromagnetic emissions from the radar apparatus could potentially interfere with commercial communications if the antenna is not properly oriented toward the ground.

Ground-penetrating radar is not suitable for use on extremely moist or wet (saturated) pavements due to attenuation of the electromagnetic signal caused by moisture.

Demonstration/Implementation Site

The U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS was selected as the site for demonstrating the use of ground-penetrating radar to determine the thickness of pavement layers. Pulse Radar, Inc., Houston, TX was awarded a contract to conduct the survey on the streets at WES. The purpose was to conduct a network level survey to collect pavement thickness data and locate utilities under the surface of the pavements. As a demonstration of their capabilities, the contractor also conducted a project level survey on one of the shorter streets. This was a detailed survey to determine the exact location of deteriorated areas beneath the pavement surface.

The contractor was furnished a map of WES that highlighted the roads to be surveyed. Prior to his arrival at WES, he created computer files for each road, and planned the priority for collecting data on the roads based on the location of start and ending points for each road, and direction of travel on one-way roads. In order for the contractor to easily find the start and ending points for each road, WES engineers marked these points on the surface of the roadways with orange paint. These reference points also allowed WES to accurately compare the results of the radar survey to roadway corings that had been obtained during the past ten or more years since their locations were defined by station numbering.

During this demonstration, data were acquired utilizing two short-pulse radar systems; one with a center frequency of one gigahertz, and the other with a center frequency of 500 megahertz. A separate antenna positioned approximately 18-inches above the roadway surface was required for each system. Each antenna collected continuous data on a 12-inch wide path for the entire length of the pavement. Location of the data collected on the roadway was

determined by a transmission-mounted encoder. The data collected at a rate of 50 data points per second was digitally stored in a 486 personal computer for processing. The processing software displayed the data in color on a monitor for the analyst to review. The van with the two antennas mounted on the front of the vehicle is shown on Figure 1.

Twenty-five streets at WES that totaled 7.3 miles in length were surveyed by the contractor within a 2-3 hour period. Twenty-four of the streets were two-lane, two-way roads that ranged in length from 90 ft to 4,693 ft. One street was a one-lane, one-way street. The results were processed and tabulated by the contractor and furnished in a final report to WES within one month after the data was collected. A tabulation of the results for one of the streets that lists the depth of each layer in the pavement structure at 50 - foot intervals, and depths and locations of utilities is shown in Table 1. The contractor also furnished the results as spreadsheet files on a floppy disk so WES engineers could display the results in graphical form. An example of the results listed in Table 1 is presented in graphical form in Figure 2.

Life Cycle Costs

The costs of implementing ground penetrating radar are based primarily on mobilization of the equipment and crew to the survey site, collection and reduction of data, and publication of a final report. Mobilization includes the movement of a van that contains the equipment and two crew members to operate the equipment and collect the data from the contractor's permanent location to the survey site. Once the contractor is on the site, he will probably ride over all of the roads to locate the start and finish points for each road and determine the priority of road selection for collecting data. Since the data can be collected at speeds of up to 40 mph, most streets on a military installation can be surveyed during a one or two day period. Evaluation of the roads on a typical military installation will cost $15 - 20K.

The Army invests many dollars to maintain the pavements infrastructure throughout the world. The PAVER system, a COE developed pavement management system, has been implemented on some installations at costs of $40 - 100K per installation. Much of this cost has been for the pavement coring required to determine the pavement thicknesses of the pavement

layers. Coring requires closing the traffic lane for 1-2 hours per core. Much of the data acquisition for both PAVER implementation and rehabilitation design are required because of a lack of as-built or inventory data on layer thicknesses. Typical construction of pavement layers can create significant variations in thickness within a given pavement segment. Even if sufficient as-built data or core data were available, the engineer designing the overlay would have no idea what this thickness would be. Knowing the thickness of the pavement layers is critical to improving the accuracy of predicting pavement performance and designing overlays.

Advantages/Benefits

A major advantage of this system is that data can be collected at near highway speeds with minimal disruption of traffic. This results in minimal traffic congestion and safety problems. There will also be a fuel savings in comparison to a coring operation for both the data collection van and the local traffic vehicles, and less potential hazards to the environment caused by exhaust emissions.

The use of ground-penetrating radar provides continuous data describing the thicknesses of the pavement layers for the entire length of the roadway, and location of water and sewer lines. Data collected with coring equipment provides only specific data at the location of the core.

3 Acquisition/Procurement

Potential Funding Sources

Typically, installations fund the implementation of pavements and railroads technologies from their annual budgets. However, the installation's annual budget is usually under funded and the pavements and railroads projects do not compete well with other high visibility or high interest projects. As a result, it is prudent to seek out additional funding sources when the project merits the action. Listed below are some sources commonly pursued to fund projects.

a. *Productivity program.* See AR 5-4, Department of the Army Productivity Improvement Program[1] for guidance to determine if the project qualifies for this type funding.

b. *Facilities Engineering Applications Program (FEAP).* In the past, a number of pavement and railroad maintenance projects located at various installations were funded with FEAP demonstration funds. At that time, emphasis was placed on demonstrating new technologies to the Directorate of Engineering and Housing (DEH) community. Now that these technologies have been demonstrated, the installations will be responsible for funding their projects through other sources. However, emphasis concerning the direction of FEAP may change in the future; therefore, one should not rule out FEAP as a source of funding.

[1] Headquarters, Department of the Army. (1976). "Department of the Army Productivity Improvement Program," Army Regulation 5-4, Washington, D. C.

c. *Special programs.* Examples of these are as follows:

(1) FORSCOM mobilization plan which may include rehabilitation or enlargement of parking areas and the reinforcement of bridges.

(2) Safety program which may include the repair of unsafe/deteriorated railroads at crossings and in ammunition storage areas.

(3) Security upgrade which may include the repair or enlargement of fencing.

d. *Reimbursable customer.* Examples of this source are roads to special function areas such as family housing or schools and airfield pavements required to support logistical operations.

e. *Special requests from MACOM's.*

f. *Year end funds.* This type of funding should be coordinated with the MACOM's to ensure that the funds will not be lost after a contract is advertised.

g. *Operations and Maintenance Army.* These are the normal funds used for funding pavement and railroad projects.

Technology Components and Sources

In general, conducting a survey on a network of roads with ground-penetrating radar is beyond the in-house capabilities of a Directorate of Public Works (DPW) office. However, the DPW office can and should provide services to prospective bidders that will enhance the final product and make the job much easier for the contractor. These services include maps marked

with the roadways to be surveyed, location of beginning and end for each road, all construction history for the roads, and any coring data that was obtained in the past. Other information should include the pavement type (portland cement concrete, asphalt concrete pavement, or overlay), estimated traffic volume, and number of lanes per road.

The use of ground penetrating radar to determine pavement thicknesses and locate utilities under roadways requires special equipment, trained operators, and experienced engineers to analyze and interpret the data obtained during a survey. Vendors experienced in this technology include:

Pulse Radar, Inc.
10665 Richmond, Suite 170
Houston, TX 77042
Office: 713/977-0557
800-551-9173
FAX: 713/977-2159

Donohue Engineers Architects, Scientists
1020 North Broadway, Suite 400
Milwaukee, WI 53202
Office: 414/271-4700
FAX: 414/271-9114

Procurement Documents

No current Corps of Engineers Guide Specification exists on the use of ground-penetrating radar to determine pavement thicknesses and locate utilities. However, there is an American Society for Testing and Materials (ASTM) test method, Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar[2], that describes the methodology of using ground-penetrating radar to survey roads for determining pavement

thicknesses.

Based on the results of this demonstration and discussions with the contractor, a suggested template for requesting bid proposals for conducting a ground-penetrating radar survey of pavement structures is provided as Appendix B.

Two factors that should be used to evaluate proposals received from prospective bidders are the qualifications and experience of the bidder. When the request for bids is advertised, a statement should be included stating that these will be two of the factors considered during the evaluation and selection process. The bidder's proposal should include a list of recent projects similar to the project being bid, and a short resume for each employee that will be working on the project.

Procurement Scheduling

There are no long lead times or special scheduling that must be considered for obtaining the services of a contractor to provide a ground-penetrating radar survey of the roads at a military installation. Normal schedules should be established to allow for contract preparation, advertisement, evaluation, and award. A contractor should be able to complete the survey of a roadway system at a typical military installation within 2-3 days.

[2] American Society for Testing and Materials. (1987). "Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar," Designation: D4748-87, Philadelphia, PA.

4 Post Acquisition

Initial Implementation

Prior to implementing this technology, decisions should be made by the DEH personnel to determine which roads and streets should be surveyed, the type of information expected from the survey, how this information will be used, and in what form (tables, graphs, spreadsheets, etc.) the results of the survey should be furnished. The contractor can also furnish the results as spreadsheet files on a floppy disk so they can be displayed in different forms at a later date. The beginning and ending of each road should be clearly marked on the roadway surface and on a map so there will be no doubt as to the location of these points by the contractor. These marks will also provide reference points for determining locations of specific items if further investigation is required.

Operation and Maintenance

DEH personnel should ensure that all roads are surveyed as specified in the contract. Results of the data collected should be incorporated into the local pavement management data base.

Service and Support Requirements

Prior to arrival of the contractor on the site, the beginning and end of each road should be marked with paint so these points can be easily seen by the driver of the vehicle used to conduct the radar survey. These marks may also be used at a later date as reference points to locate specific pavement features that were detected during the survey. No special services or support are required to maintain this technology.

Performance Monitoring

DEH personnel should determine the accuracy of the survey results by comparing pavement layer thickness determinations to known pavement thicknesses. These known thicknesses can be obtained from old pavement corings, construction drawings, or information collected during pavement repairs and utility cuts.

Appendix A

Fact Sheet

TECHNIQUE: Ground-Penetrating Radar

DESCRIPTION:

Ground- penetrating radar is a system that utilizes short pulse radar to nondestructively measure the thicknesses of composite structural sections. The detection of an interface between two different materials by radar depends upon the partial reflection of incident energy at that interface. The amplitude of the reflected energy at the interface, with respect to the incident energy, is related to the relative dielectric constants of the two materials. Pavement layer thicknesses can be determined if the dielectric constants of the materials and the time required for radar waves to pass through the layers and return are known.

Current systems are contained in a van size truck that travels at 5-40 miles per hour while collecting data. As the data is collected in a traffic lane, distances are measured and marked for a reference system. Output is furnished the user in report form to include location and thicknesses of the surface and base course materials and the location and depth of utilities.

AREAS OF APPLICATION:

In recent years the emphasis on pavement construction has moved toward rehabilitating or strengthening existing structures rather than constructing new facilities. Selection of the correct rehabilitation strategy depends on a detailed evaluation of the existing pavement structure. Nondestructive testing using a falling weight deflectometer is the principal tool used to perform this evaluation. However, to perform the layer strength back calculation procedure, the thickness of pavement layers and presence of bedrock close to the surface is required. Layer thicknesses are sometimes available from construction plan sheets, but they are frequently either not available or not current. The alternative is spot coring which is expensive and time consuming. Ground penetrating radar has the potential to determining layer thicknesses, locate bedrock, and locate sewer and water lines buried to depths of approximately four feet. A major advantage of this system is that data can be collected at near highway speeds with minimal disruption of traffic. This results in minimal traffic congestion and safety problems.

PHYSIOGRAPHIC FACTORS:

The radar apparatus used in this technology is potentially a microwave radiation hazard, especially at high transmitted power levels. All personnel should stand clear of the region directly under the antenna when the system is energized. Electromagnetic emissions from the radar apparatus could potentially interfere with commercial communications if the antenna is not properly oriented toward the ground.

DISCUSSIONS AND RECOMMENDATIONS:

Ground penetrating radar is recommended for use in determining thicknesses of pavement structures at military installations. In recent years in order to save money, pavement structures have been rehabilitated or strengthened to withstand expected traffic rather than

construct new facilities. Selection of the correct rehabilitation strategy depends on a thorough evaluation of the existing pavement structure. Nondestructive testing, particularly using falling weight deflectometers, is the main tool for performing this evaluation. In order to back calculate pavement layer strengths, the thickness of the pavement layers and presence and location of bedrock close the surface is required. Layer thicknesses are sometimes available from plan sheets but they are frequently either not available or not current. The alternative is spot coring which is time consuming, expensive, and requires traffic to be detoured during the coring operation.

SUMMARY:

Ground-penetrating radar is a system that can be used to rapidly identify vertical structural characteristics and the general subsurface condition of a pavement structure and locate utilities buried to depths of approximately four feet.

REFERENCES:

ASTM D 4748-87, Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar.

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Appendix B
Recommended Specifications Template

Recommended Specifications Template for Request for Bid

1. GENERAL.

The contractor shall provide all supplies, labor, and equipment to conduct short-pulse radar survey on streets located on (name of military installation). A report that includes an introduction, a general description and methodology of the system, radar chart output example, results, and data tables shall be provided.

Note: The contractor may also be required to furnish the results on a computer disk in a specific spread sheet format so they can be displayed differently after the contract is completed.

2. GOVERNMENT RESPONSIBILITIES.

a. The Directorate of Public Works (DPW) shall determine the level of survey required.

1. General subsurface and vertical structural conditions are obtained during a network level survey.
2. Location of utilities (mainly sewer and water lines) can also be determined during a network level survey.
3. Detailed location of deteriorated areas can be determined during a project level survey.

b. The DPW shall furnish a tabulation of streets to be evaluated. The table shall include the following: names of streets, length, location (beginning and ending points), number of lanes, and surface classification.

c. The DPW shall furnish a map that displays the location of each street to be surveyed.

3. CONTRACTOR RESPONSIBILITIES.

a. Field Work. The street survey and pavement thickness determinations shall be made in accordance with the methodology described in ASTM D 4748, Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar.

b. Material Properties. Sufficient cores shall be obtained from each type of pavement structure so accurate dielectric constants can be determined for representative pavement layer materials.

c. Traffic Control. If traffic control is required, the contractor shall be responsible.

Traffic control shall be in accordance with the Manual of Uniform Traffic Control Devices.

d. Any liability due to accidents associated with the field testing or survey shall be provided by the contractor.

e. Report. The final report shall include as a minimum an introduction, methodology, radar chart output example, general discussion of results, and a tabular listing of data acquired on a street by street basis. The standard procedure for providing results is to include a tabulation for each street that lists the depths of each layer in the pavement structure at 50 - foot intervals. Also included in the table are depths and distances from station 0+00 for each utility, bridge deck, apparent material changes, and well-defined pavement changes. The results can also be presented in graphical form so plots of the various structural layers, utilities, and other features can be easily visualized. This information can be saved in a spread sheet format on a floppy disk so it can be displayed in other forms at a later date.

4. AREAS TO BE TESTED.

A prioritized list of streets to be surveyed, their locations, and descriptions are provided as attached.

5. PREMEETING.

Prior to initiating the work, representatives from the DPW and the contractor shall meet to coordinate testing and surveying of the streets. During this meeting the beginning and ending points of any streets in question should be discussed and their locations mutually agreed to.

Appendix C
Figures

Figure 1. Survey van with antennas mounted

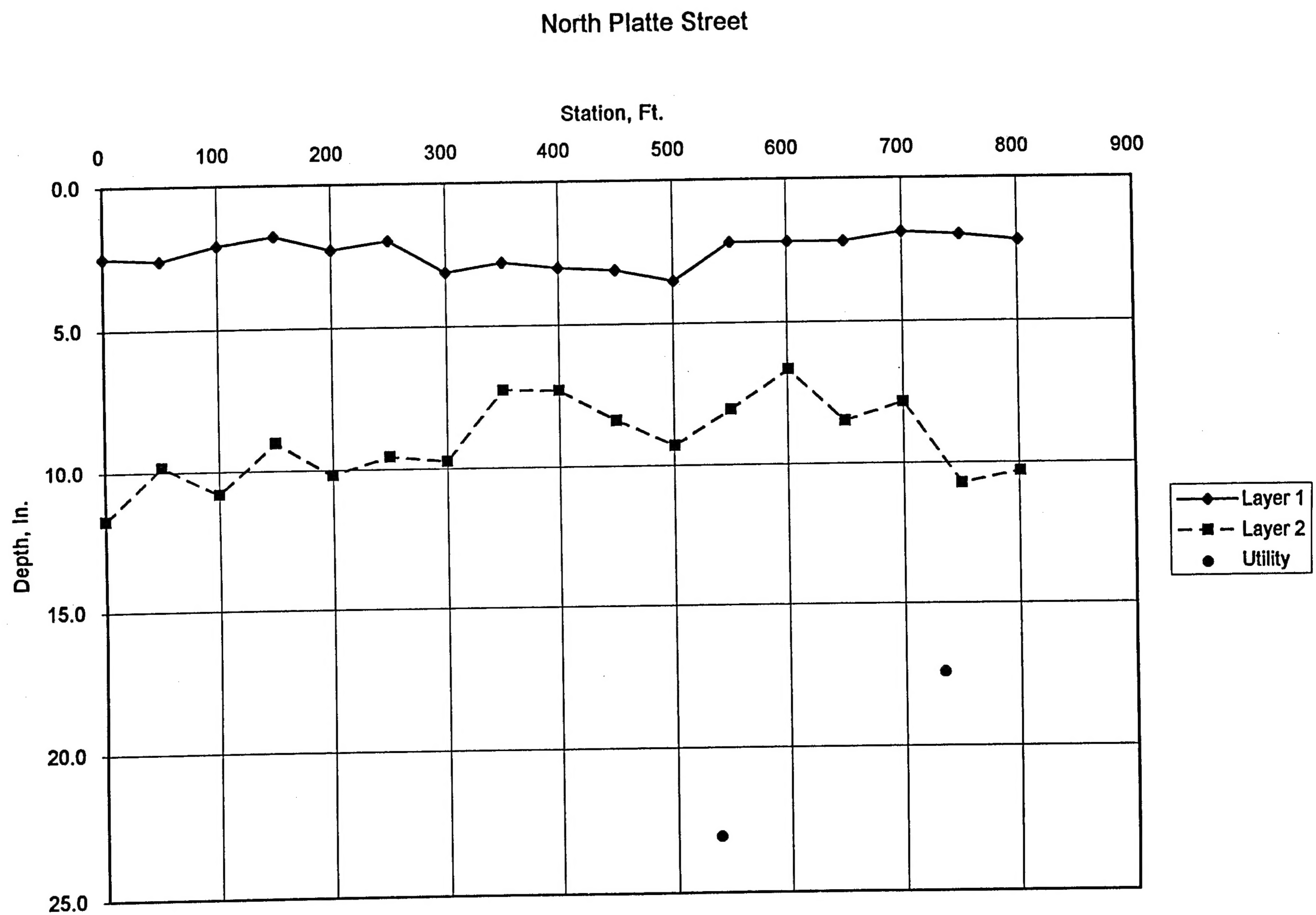

Figure 2. Example of Survey Results Provided in Graphical Form

Appendix D
Table

Table 1
Example of Survey Results Provided in Spreadsheet Form

Run Date: 3/30/95
North Platte Street
Start Columbia Road
Stop Porters Chapel Road
Antenna Placement: LWP 1 GHZ RWP 500 MHZ

Type	Ft1	Depth	epsilon
L1	0	2.5	6.5
L2	0	9.2	9.2
L1	50	2.6	6.5
L2	50	7.2	9.2
L1	100	2.1	6.5
L2	100	8.7	9.2
L1	150	1.8	6.5
L2	150	7.2	9.2
L1	200	2.3	6.5
L2	200	7.9	9.2
L1	250	2.0	6.5
L2	250	7.6	9.2
L1	300	3.1	6.5
L2	300	6.6	9.2
L1	350	2.8	6.5
L2	350	4.5	9.2
L1	400	3.0	6.5
L2	400	4.3	9.2
L1	450	3.1	6.5
L2	450	5.3	9.2
L1	500	3.5	6.5
L2	500	5.8	9.2
L1	550	2.2	6.1
L2	550	5.9	7.5
L1	600	2.2	6.1
L2	600	4.4	7.5
L1	650	2.2	6.1
L2	650	6.3	7.5
L1	700	1.9	6.1
L2	700	6.0	7.5
L1	750	2.0	6.1
L2	750	8.7	7.5
L1	800	2.2	6.1
L2	800	8.1	7.5
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UT	734	17.4	8.0